

Written review of the official reviewer on the dissertation submitted for the degree of Doctor of Philosophy (PhD)
by UKUBAYEV TEMIRLAN ALIBIEVICH

on the topic: «Incorporating system dynamic modeling in infection transmission of tuberculosis»
in the educational program 8D10139 – «Public Health»

№	Criteria	Compliance with the criteria (underline one of the answer options)	Justification of the official reviewer's position (comments should be italicized)
1.	The dissertation topic (as of the approval date) corresponds to the directions of scientific development and/or state programs	1.1 Compliance with priority areas of scientific development or state programs: 1) the dissertation was completed within the framework of a project or target program financed from the state budget (indicate the name and number of the project or program); 2) the dissertation was completed within the framework of another state program (indicate the name of the program); 3) <u>the dissertation corresponds to the priority area of scientific development approved by the Higher Scientific and Technical Commission under the Government of the Republic of Kazakhstan (indicate the area).</u>	<i>The topic of the dissertation research is fully aligned with contemporary public health priorities and the international agenda for tuberculosis control. The World Health Organization (WHO) places special emphasis on tuberculosis as one of the leading infectious causes of mortality worldwide and has established strategic objectives for substantially reducing TB incidence and mortality through the global End TB Strategy.</i> <i>The relevance of this research is further underscored by the fact that, in April 2025, the WHO officially launched the regional initiative "TB-Free Central Asia" in Astana, aimed at the complete elimination of tuberculosis and its drug-resistant forms in Central Asian countries by 2030. In this context, the present study possesses significant scientific and practical value, as it examines not only the epidemiological aspects of the disease but also the influence</i>

			<i>of socioeconomic factors that play a critical role in the spread of tuberculosis and the effectiveness of control measures.</i> <i>The research is consistent with the national priorities of the Republic of Kazakhstan in strengthening public health, improving epidemiological forecasting, and enhancing the effectiveness of preventive interventions.</i>
2.	Importance for science	The work <u>makes</u> /does not make a significant contribution to science, and its importance is <u>well disclosed</u> /not disclosed.	<i>The dissertation research is of considerable scientific interest, as it is the first study in the Republic of Kazakhstan to develop a tuberculosis transmission model based on a system dynamics approach. The proposed framework enables a comprehensive analysis of the epidemic process as a dynamic system influenced not only by medical determinants but also by a wide range of socioeconomic factors.</i> <i>The scientific significance of the study lies in the model's ability to quantitatively assess the impact of various socioeconomic indicators on tuberculosis incidence, analyze long-term epidemiological trends, and forecast the outcomes of different intervention scenarios. The model provides a robust analytical tool for understanding the complex interactions that shape the dynamics of tuberculosis transmission.</i>

			<i>The practical value of the model is reflected in its potential application by regulatory and public health authorities to support evidence-based decision-making and to identify the most effective interventions for achieving the World Health Organization's target indicators for reducing tuberculosis incidence.</i>
3.	Principle of independence	Level of independence: 1) high; 2) medium; 3) low; 4) no independence.	<i>The doctoral candidate demonstrated a high level of independence throughout the research process. As part of the study, the candidate collected and systematized an extensive body of statistical data covering a prolonged observation period, including information on tuberculosis incidence, mortality, treatment outcomes, disease recurrence, and key socioeconomic indicators.</i> <i>The author independently reviewed and analyzed existing approaches to the mathematical modeling of infectious diseases and selected and adapted an appropriate tuberculosis transmission model for the specific conditions of the Republic of Kazakhstan. The doctoral candidate carried out all stages of model parameterization, calibration, and validation, demonstrating a high level of proficiency in contemporary</i>

			methods of mathematical and epidemiological analysis. Particularly noteworthy is the independent implementation of various intervention scenarios aimed at achieving the target indicators established by the World Health Organization, as well as the author's thorough analysis and interpretation of the modeling results. The practical significance of the study is evidenced by the implementation of its findings in the activities of healthcare organizations and in the educational process, as well as by the acquisition of a copyright certificate for an intellectual property object.
4	Principle of internal unity	4.1 Justification of the relevance of the dissertation: 1) <u>justified</u>; 2) partially justified; 3) not justified. 4.2 The content of the dissertation reflects the dissertation topic: 1) <u>reflects</u>; 2) partially reflects; 3) does not reflect. 4.3. The goal and objectives correspond to the dissertation topic: 1) <u>correspond</u>;	The dissertation is characterized by a high degree of internal consistency, logical coherence, and methodological integrity. All sections of the study are united by a common scientific objective: the development and application of a system dynamics model of tuberculosis transmission to assess the impact of socioeconomic factors and to forecast the epidemiological situation. In the literature review, the author systematically substantiates the relevance of the research topic, highlighting the need to incorporate modern mathematical modeling

		2) partially correspond; 3) do not correspond.	<i>approaches and socioeconomic determinants into tuberculosis research. In the subsequent stage, the doctoral candidate developed and validated a tuberculosis transmission model tailored to the specific conditions of the Republic of Kazakhstan. The study further presents a mathematical model describing the influence of socioeconomic factors on the tuberculosis transmission coefficient, enabling a quantitative assessment of their contribution to disease dynamics. In the following chapters, the author identifies the optimal levels of key socioeconomic factors required to achieve the target indicators established by the World Health Organization and examines various scenarios for forecasting tuberculosis incidence through 2030. Based on the findings obtained, the author formulates practical recommendations aimed at enhancing the effectiveness of tuberculosis control measures and improving decision-making processes in the field of public health management.</i>
		4.4 All sections and provisions of the dissertation are logically interconnected: 1) <u>fully interconnected</u> ; 2) partially interconnected; 3) no interconnection.	
		4.5 The new solutions (principles, methods) proposed by the author are reasoned and evaluated in comparison with known solutions: 1) <u>critical analysis is present</u> ; 2) the analysis is partial; 3) the analysis consists not of the author's own opinions, but of quotations from other authors; 4) the analysis is absent.	
5	Principle of scientific novelty	5.1 Are the scientific results and provisions new? 1) <u>completely new</u> ; 2) partially new (25–75% are new); 3) not new (less than 25% are new).	<i>The scientific novelty of the dissertation lies in several findings that contribute to the advancement of contemporary epidemiology and the mathematical modeling of infectious</i>

		5.2 Are the conclusions of the dissertation new? 1) <u>completely new</u>; 2) partially new (25–75% are new); 3) not new (less than 25% are new).	<i>diseases. First and foremost, the study presents the first system dynamics model of tuberculosis transmission developed and implemented specifically for the Republic of Kazakhstan. Unlike conventional statistical approaches, the proposed model incorporates not only classical epidemiological parameters but also the influence of socioeconomic factors on the dynamics of the epidemic process. This framework enables the analysis of long-term changes in tuberculosis incidence and the assessment of the potential outcomes of various policy and management interventions.</i> <i>Another novel scientific contribution is the establishment of a quantitative relationship between the tuberculosis transmission coefficient and key socioeconomic determinants, including poverty levels, unemployment rates, healthcare financing, and the extent of social support provided to patients. The author demonstrates that changes in these factors exert varying degrees of influence on the spread of tuberculosis, thereby enabling a transition from descriptive analysis to a quantitative assessment of the contribution of</i>
		5.3 Technical, technological, economic, or managerial solutions are new and justified: 1) <u>completely new</u>; 2) partially new (25–75% are new); 3) not new (less than 25% are new).	

			<i>socioeconomic determinants to the epidemiological process.</i> <i>Of particular scientific interest is the scenario analysis conducted within the study, in which different socioeconomic intervention strategies were modeled for the first time to evaluate their potential for achieving the World Health Organization's target indicators for reducing tuberculosis incidence by 2030. The author identified the optimal values of key socioeconomic parameters under which the achievement of the WHO's strategic targets becomes feasible.</i> <i>Therefore, the dissertation contains elements of scientific novelty both in the field of epidemiological modeling and in the development of decision-support tools for public health policy and management.</i>
6	Validity of the main conclusions	All main conclusions <u>are</u> /are not based on scientifically significant evidence or are sufficiently substantiated (for qualitative research and training areas in arts and humanities).	<i>The conclusions presented in the dissertation are well substantiated and supported by the findings of the study reported in the corresponding sections of the work. Each conclusion logically follows from the statistical analyses, mathematical modeling results, and scenario-based simulations conducted by the author.</i>

			<i>The first conclusion, stating that the rate of decline in tuberculosis incidence in Kazakhstan has slowed in recent years and that socioeconomic factors make a substantial contribution to the dynamics of the epidemic process, is based on the analysis of tuberculosis incidence trends during the period 2000–2024, presented in Section 3.1. In Subsections 3.1.1 and 3.1.2, the author analyzes long-term incidence trends and quantitatively evaluates the influence of socioeconomic factors on changes in tuberculosis indicators.</i> <i>The second conclusion, concerning the validity and reliability of the developed model as a tool for forecasting tuberculosis incidence, is supported by the results presented in Sections 3.2 and 3.3. These sections describe the stages of model parameterization, calibration of key coefficients, and validation procedures, including an assessment of predictive accuracy through comparisons between simulated and observed epidemiological indicators.</i> <i>The third conclusion, regarding the high sensitivity of the model to parameters such as healthcare financing and unemployment</i>
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			levels, is based on the sensitivity analyses and assessments of socioeconomic determinants presented in Sections 3.4 and 3.5. The author demonstrates that variations in these parameters exert the strongest influence on the transmission coefficient and on projected tuberculosis incidence rates. The fourth conclusion, which identifies increased social support for tuberculosis patients as one of the most effective long-term measures for reducing disease incidence, is substantiated by the results of the scenario analyses presented in Subsections 3.7.1–3.7.6. The author compares various socioeconomic intervention strategies and evaluates their impact on projected tuberculosis incidence through 2035. The fifth conclusion, emphasizing the need for comprehensive socioeconomic improvements, increased healthcare financing, and strengthened social support measures to achieve the target indicators established by the World Health Organization, is derived from the findings presented in Section 3.8. This section provides estimates of the optimal socioeconomic parameter values required to
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			attain the strategic objectives of the End TB Strategy by 2030 and 2035. Overall, all major conclusions of the dissertation are supported by the results of statistical analyses, mathematical modeling, and scenario-based forecasting conducted using contemporary data analysis techniques and system dynamics methodologies.
7	Main provisions submitted for defense	It is necessary to answer the following questions separately for each provision: 7.1 Has the provision been proven? 1) <u>proven</u>; 2) rather proven; 3) rather not proven; 4) not proven; 5) in the current wording, it is impossible to verify whether the provision has been proven. 7.2 Is it trivial? 1) yes; 2) <u>no</u>; 3) in the current wording, it is impossible to verify whether the provision is trivial. 7.3 Is it new? 1) <u>yes</u>; 2) no; 3) in the current wording, it is impossible to verify the novelty of the provision. 7.4 Level of application:	<i>The first proposition, concerning the development of a system dynamics model of tuberculosis transmission in the Republic of Kazakhstan, is genuinely novel and represents a valuable contribution to contemporary epidemiological research. Unlike traditional statistical and time-series models, the proposed framework incorporates the influence of socioeconomic factors on the tuberculosis transmission coefficient and enables the analysis of the long-term dynamics of the epidemic process. The model was implemented using a system dynamics approach, calibrated to national data from Kazakhstan, and validated against observed epidemiological indicators, thereby confirming its reliability and practical applicability (Sections 3.2–3.3).</i> <i>The second proposition, which highlights the significant impact of socioeconomic factors</i>

		1) narrow; 2) medium; 3) <u>broad</u>; 4) in the current wording, it is impossible to verify the level of application of the provision. 7.5 Has it been proven in the article? 1) <u>yes</u>; 2) no; 3) in the current wording, it is impossible to verify whether the provision has been proven in the article.	<i>on tuberculosis incidence dynamics, logically follows from the results of the modeling and statistical analyses. For the first time, the author established a quantitative relationship between the infection transmission coefficient and such indicators as poverty levels, unemployment rates, healthcare financing, and social support for patients. This proposition is supported by the results of correlation analysis, regression modeling, and sensitivity analysis of the developed model (Sections 3.4–3.5).</i> <i>The third proposition, concerning the evaluation of various socioeconomic intervention scenarios aimed at achieving the target indicators established by the World Health Organization, is of both scientific and practical importance. The author performed numerical simulations of different socioeconomic development scenarios and demonstrated their impact on projected tuberculosis incidence through 2030–2035. These findings provide a valuable evidence base for the development of strategic decisions and tuberculosis control programs (Section 3.7).</i>
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			<i>The fourth proposition, regarding the feasibility of achieving WHO targets through comprehensive improvements in socioeconomic conditions and strengthened social support measures, is also well substantiated and supported by the results of optimization modeling. In Section 3.8, the author identifies the most effective combinations of socioeconomic parameters required to approach the strategic targets of the End TB Strategy.</i> <i>It should be emphasized that all propositions submitted for defense are supported by the author's original research findings, have been published in international peer-reviewed journals, and possess substantial practical relevance for public health management and epidemiological forecasting.</i>
8	Principle of reliability. Reliability of sources and the information provided.	8.1 The choice of methodology is justified or the methodology is described in sufficient detail: 1) <u>yes</u>; 2) no. 8.2 The results of the dissertation research were obtained using modern scientific research methods and techniques for data processing and	<i>The reliability of the dissertation findings is ensured through a comprehensive combination of methodological and analytical approaches. The selected methodology is well justified and fully consistent with contemporary standards in public health research and mathematical epidemiology. The author employed well-</i>

		interpretation with the use of computer technologies: 1) <u>yes</u>; 2) no.	<i>established statistical and mathematical modeling techniques that are widely used in international studies of infectious diseases. Particular attention should be given to the quality of the data sources used in the study. The research database was compiled from official and internationally recognized sources, including data from the World Health Organization, the World Bank, the Bureau of National Statistics of the Republic of Kazakhstan (stat.gov.kz), and the National Scientific Center for Phthisiopulmonology of the Republic of Kazakhstan. The use of these sources ensures a high level of reliability, comparability, and representativeness of the underlying data. The literature review is based primarily on recent scientific publications from leading international peer-reviewed journals. The author analyzed a broad range of sources covering tuberculosis epidemiology, social determinants of health, system dynamics, and the mathematical modeling of infectious diseases. This demonstrates a thorough understanding of the current state of knowledge in the field and ensures the relevance and robustness of the study's theoretical foundation.</i>
		8.3 Theoretical conclusions, models, identified relationships, and patterns have been proven and confirmed by experimental research (for pedagogical sciences, the results are proven on the basis of a pedagogical experiment): 1) <u>yes</u>; 2) no.	
		8.4 Important statements are <u>confirmed</u>/partially confirmed/not confirmed by references to relevant and reliable scientific literature.	
		8.5 The literature sources used are <u>sufficient</u>/insufficient for the literature review.	

			<i>The developed model is based on classical epidemiological approaches derived from compartmental models of the SIR type, whose effectiveness has been repeatedly demonstrated in international infectious disease modeling research. At the same time, the author proposes an original adaptation of the model to the context of the Republic of Kazakhstan through the incorporation of socioeconomic factors, thereby enhancing its practical applicability and scientific value.</i> <i>The reliability of the findings is further supported by a complete process of model verification and validation. The author conducted parameter calibration, predictive performance testing, sensitivity analyses, and comparisons between simulated outputs and observed epidemiological data. The results demonstrated a high degree of agreement with real-world observations, confirming both the validity of the model and the soundness of the conclusions drawn from it.</i> <i>Additional evidence of the reliability and scientific significance of the research findings is provided by their dissemination within the international scientific community. The principal results of the</i>
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			<i>dissertation have been published in international peer-reviewed journals indexed in the Scopus and Web of Science databases. Publication in these journals implies successful independent scientific peer review and confirms that the research meets contemporary international standards for scientific quality and rigor.</i> <i>Overall, the reliability of the source data, the application of contemporary and internationally recognized scientific methods, the use of validated epidemiological modeling approaches, the completion of rigorous verification procedures, and the international publication of the findings collectively support the conclusion that the dissertation results are scientifically sound, well substantiated, and credible.</i>
9	Principle of practical value	9.1 The dissertation has theoretical significance: 1) <u>yes</u>; 2) no. 9.2 The dissertation has practical significance and there is a high probability of applying the obtained results in practice: 1) <u>yes</u>; 2) no. 9.3 The proposals for practice are new:	<i>The dissertation research possesses substantial theoretical and practical significance. The practical value of the study lies primarily in the fact that the author has developed specific recommendations for regulatory authorities and the healthcare system aimed at achieving the World Health Organization's target indicators for reducing the incidence of tuberculosis and its</i>

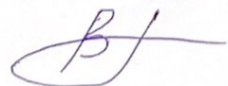
		1) <u>completely new</u>; 2) partially new (25–75% are new); 3) not new (less than 25% are new).	<i>drug-resistant forms. Based on the modeling results, the author demonstrates the necessity of a comprehensive approach that includes increased healthcare financing, reductions in unemployment and poverty levels, and the expansion of social support measures for tuberculosis patients. Particular emphasis is placed on enhancing social assistance programs for patients, which are identified as one of the most effective long-term interventions for reducing the spread of the disease.</i> <i>The practical significance of the research is further supported by the development of management intervention scenarios that enable the assessment of the potential consequences of various socioeconomic policy decisions on the epidemiological situation. The proposed model can be utilized by public health authorities to forecast tuberculosis trends, evaluate the effectiveness of implemented measures, and support evidence-based strategic decision-making in tuberculosis control programs.</i> <i>The findings of the dissertation have been implemented in the practical activities of the Regional Phthisiopulmonology Center, where the developed model is used as an</i>
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			<i>analytical tool for assessing and forecasting the epidemiological situation of tuberculosis. Its implementation contributes to more informed resource allocation, improved planning of preventive measures, and enhanced effectiveness of management decisions.</i> <i>Furthermore, the results of the study have been incorporated into the educational process of the Department of Infectious Diseases and Phthisiology at Karaganda Medical University. The developed model serves as a modern educational tool for training students in public health, epidemiology, and phthisiology. Its application facilitates the development of practical skills in analyzing epidemiological processes, interpreting forecast data, and assessing the impact of socioeconomic factors on the spread of infectious diseases.</i> <i>An additional indication of the practical significance of the research is the author's receipt of a certificate of state registration for the intellectual property object associated with the developed model.</i>
10	Quality of writing and formatting	Quality of academic writing: 1) high ; 2) average;	<i>The dissertation is written at a high academic standard and is characterized by logical consistency, coherence, and a well-</i>

		3) below average; 4) low.	<i>structured presentation of the material. The author demonstrates a strong command of the terminology and concepts related to public health, epidemiology, mathematical modeling, and simulation-based analysis. At the same time, the writing style remains clear, accessible, and understandable for both specialists in medicine and epidemiology and researchers working in the fields of modeling and complex systems analysis.</i> <i>This reflects the author's ability to effectively interpret interdisciplinary scientific findings and present them in a manner that is both scientifically rigorous and practically applicable. The dissertation is prepared in accordance with established academic and formatting requirements, while the tables, diagrams, and graphical materials included in the work contribute significantly to the clarity of the presentation and facilitate a better understanding of the study's findings and conclusions.</i>
11	Comments on the dissertation	<i>The dissertation fully complies with the requirements established for doctoral dissertations.</i>	
12	Scientific level of the doctoral student's articles on the research	<i>The scientific quality of the doctoral candidate's publications related to the dissertation topic is high and meets the requirements established for PhD-level research. The principal findings of the study have been published in international peer-reviewed scientific journals indexed in the</i>	

	topic (in the case of dissertation defense in the form of a series of articles, official reviewers comment on the scientific level of each article by the doctoral student on the research topic)	<i>reputable Scopus and Web of Science databases. The publication of the research outcomes in journals with strong international standing confirms the scientific significance, relevance, and scholarly impact of the study within the international research community.</i> <i>The published articles reflect the key contributions of the dissertation, including the development of a system dynamics model of tuberculosis transmission, the assessment of the impact of socioeconomic factors, and the results of scenario-based forecasting. This demonstrates that the research findings have undergone an appropriate level of scientific validation and dissemination and are consistent with contemporary international standards for academic publication.</i>
13	Decision of the official reviewer (according to paragraph 28 of these Standard Regulations)	<i>Award the degree of Doctor of Philosophy (PhD) in the educational program 8D10139 – Public Health.</i>

Official reviewer:



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